THE
ONTARIO WATER RESOURCES
COMMISSION

STATUS OF ENRICHMENT

of

RILEY LAKE

TOWNSHIP OF RYDE

1970

Water management in Ontario

Ontario
Water Resources
Commission

135 St. Clair Ave. W.
Toronto 7, Ontario
Tel. 248-30.

Division of
Laboratories,
Box 213,
Rexdale, Ont.

May 18, 1971.

Dear Sir:

The enclosed report entitled "Status of Enrichment of Riley Lake" was prepared by personnel of the Biology Branch of the Commission in connection with a co-operative study involving the Department of Health, Hough Stansbury and Associates Limited, Landscape Architects and Site Planners and the OWRC.

This report on limnological characteristics indicates the eutrophic condition of Riley Lake and points out that cottage wastes, including seepage from septic tank systems, are the only potential source of artificial nutrients to the lake. The study demonstrates the immediate need for elimination of domestic wastes and artificial nutrient seepage by total retention or treatment of cottage wastes in a manner which will not affect the lake. Future shoreline development should not be permitted unless facilities are provided which will prevent any translocation or seepage of organic wastes, bacteria and/or nutrients to the lake.

It should be stressed that the entire problem of sub-surface waste disposal is extremely complex and further experimentation may be required to ensure that adequate criteria and guidelines are developed for determining the suitability of cottage waste treatment systems in cottage areas throughout the Precambrian Shield.

Please do not hesitate to contact us should you have any questions pertaining to this study. Additional copies of the report are available upon request.

Yours very truly,

for J.H. Neil,
Director,
Division of Laboratories.

MFPM/ml

STATUS OF ENRICHMENT

OF

RILEY LAKE - TOWNSHIP OF RYDE

1970

by

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Biology Branch

December, 1970

"A lake is the landscape's most beautiful and expressive feature. It is earth's eye; looking into which the beholder measures the depth of his own nature." Henry David Thoreau

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SUMMARY AND CONCLUSIONS

Classical indications of eutrophy in Riley Lake were evinced by extremely low Secchi disc readings, oxygen depletions and high phosphorus, nitrogen, iron and silica concentrations in the lower waters; depression of pH in the deeper strata; and by high standing stocks of phytoplankton dominated by the blue-green "water-bloom" species of algae *Aphanizomenon flos-aquae* and *Anabaena* spp. Relatively high rates of carbon assimilation (as detected using the ^{14}C uptake method) as well as the shape of the vertical assimilation curve reflected the eutrophic nature of the lake.

This study was not designed to provide a definite indication of the underlying causes of the present degree of enrichment in Riley Lake. However, over the past three years enrichment studies have been carried out by personnel of the OWRC on a number of similarly affected lakes. Cottage wastes, including seepage from septic tank systems, are the only potential source of artificial nutrients to these lakes. While efficiently functioning septic tanks may adequately curb bacterial contamination and artificial nutrient enrichment, it is obvious that many systems have been installed where local conditions (soil depth and permeability, slope, vegetative cover, depth to water table, distance to lake, etc.) are unsatisfactory.

Household synthetic detergents which have contained up to 50% phosphorus by weight (as phosphate) have been one of the major potential causes of enrichment in recreational lakes. Phosphorus, an element which is considered to be the critical nutrient for algal growth, may gain access to the lake as a result of some washing activities where cottage waste treatment facilities are inadequate.

RECOMMENDATIONS

1. Future shoreline development on Riley Lake should not be permitted unless facilities are provided which will prevent any translocation or seepage of organic wastes, bacteria and/or nutrients to the lake.

2. There are numerous cottages now developed in situations where adequate nutrient and/or bacterial containment is not being provided (i.e. bald rock areas and small islands). Research must be implemented to demonstrate the suitability of alternatives and/or modifications to existing septic tank tile-field systems where these cannot be expected to function adequately. Also, municipal officials in co-operation with Provincial government agencies must take the initiative to ensure the provision of an adequate collection and disposal system which would render total containment - pump out facilities a practical solution to waste disposal in difficult areas.

3. The use of washing compounds containing phosphates should be avoided. Most household liquid dishwashing products do not contain phosphates and so do not contribute to feeding algae. If clothes washing is carried out at summer cottages it is not necessary to use granular detergents containing phosphates, since ordinary soap products perform adequately in water from soft-water lakes. Although the phosphate content of all household detergents has been reduced to approximately 20% as P_2O_5 (effective August, 1970), the exclusive use of laundry soaps would provide a significant reduction in the potential enrichment by phosphates.

GLOSSARY OF TERMS

ALGAE - an assemblage of simple, mostly microscopic non-vascular plants containing photosynthetic pigments such as chlorophyll. Algae occur suspended in water (phytoplankton) and as filaments attached to rocks and other substrates. Some algae may produce nuisance conditions when environmental conditions are suitable for prolific growth.

BIOTA - all living organisms in a region.

BLUE-GREEN ALGAE - a group of algae with a blue-pigment, in addition to the green pigment - chlorophyll. A foul odour is often associated with the decomposition of dense 'water-blooms' of blue-green algae in fertile lakes.

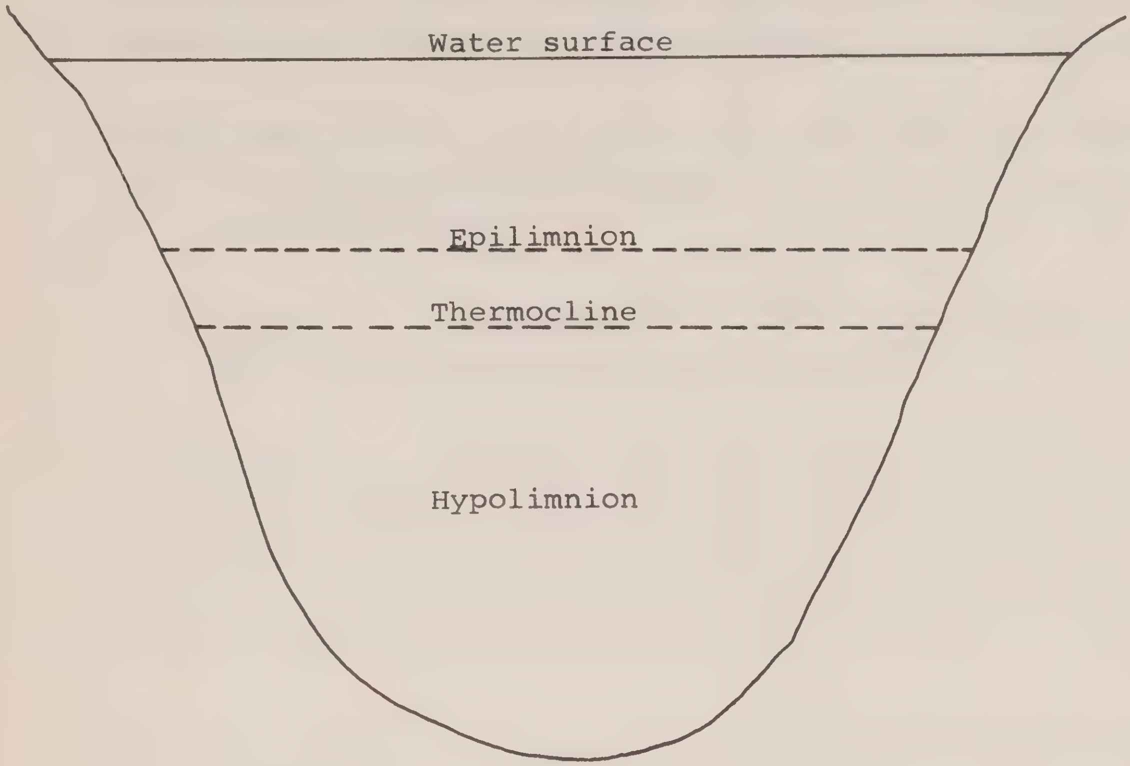
CLINOGRADE - a type of vertical oxygen distribution in a lake involving depletion of oxygen levels in the deeper waters.

DIATOMS - one of the most important groups of microscopic algae found in freshwater. Diatoms are distinguished by their silica cell walls (consisting of two halves, one fitting into the other like a box and its lid) and by their yellow or brown colour.

DISSOLVED OXYGEN - atmospheric oxygen which is dissolved in water and can be expressed as parts per million or percent saturation.

EPILIMNION - the uniformly warmer and turbulent superficial layer of a lake when it is thermally stratified during the summer. The layer above the thermocline(Figure i).

EUPHOTIC ZONE - the lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration.



EPILIMNION - the warm (higher) upper layer of water

THERMOCLINE - the transition layer of rapid temperature change between the upper warm layer and the deep cold water

HYPOLIMNION - the deep cold (heavier) water zone below the thermocline

Figure i. Section of Riley Lake showing the three layers resulting from thermal stratification.

EUTROPHICATION - The intentional or unintentional enrichment of a lake or stream owing to the presence of essential plant nutrients such as phosphorus and nitrogen.

FLAGELLATED ALGAE - a group of algae which have one or more whip-like appendages (flagella) per cell. The flagella are used for movement.

GREEN ALGAE - a group of algae which have pigments similar in colour to those of higher green plants.

HYPOLIMNION - the uniformly cold and deep layer of a lake when it is thermally stratified during the summer. The hypolimnion is below the thermocline (Figure i) and is generally removed from the surface influence (i.e. does not receive oxygen from the atmosphere).

LUGOL'S IODINE - a preservative for algae containing potassium iodide, iodine and water.

m - metre

$mgC/m^3/hr.$ - milligrams of carbon assimilated per cubic metre per hour.

$mgC/m^2/hr.$ - milligrams of carbon assimilated per square metre per hour; the amount of carbon fixed per square metre of euphotic zone.

MICRON - a unit of measurement equal to 0.001 millimetres.

ml - millilitre

ORTHOSILICATE - silica in water is detected as orthosilicate; the results recorded in this report represent only the molybdate-reactive portion of soluble silica. Silica is present in

natural waters in soluble and colloidal forms. A silica cycle occurs in many bodies of water containing organisms, such as diatoms which utilize silica in their skeletal structure. The silica removed from the water by the diatoms may be slowly returned by re-solution of the dead organisms.

pH - a means of expressing the degree of acidity or basicity of a solution. At normal temperature, neutral solution such as pure distilled water has a pH of 7, a basic solution has a pH greater than 7 and an acidic solution has a pH less than 7.

PHOTOSYNTHESIS - the process by which simple sugars are manufactured from carbon dioxide and water by living plant cells with the aid of chlorophyll in the presence of light.

PHYTOPLANKTON - free-floating microscopic algae which are slightly motile and exist at or near neutral bouyancy.

PLANKTON - an assemblage of micro-organisms, both plant and animal, that either have relatively small powers of locomotion or drift in the water subject to the action of waves and currents.

PRIMARY PRODUCTIVITY - the rate of photosynthetic carbon fixation by plants and bacteria forming the base of the food chain.

SECCHI DISC - a circular metal plate, 20 centimetres in diameter, the upper surface of which is divided into four equal quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white. The Secchi disc is used to estimate the depth of the euphotic zone.

SEDGWICK-RAFTER COUNTING CELL - a plankton-counting cell consisting of a brass or glass receptable 50 x 20 x 1 millimetres sealed to a 1 x 3 inch glass microscope slide. A rectangular cover glass large enough to cover the whole cell is required. The cell has a capacity of exactly 1 millilitre.

STANDING STOCK - the biota present in an environment at a selected point in time.

THERMAL STRATIFICATION - in the spring, vertical temperatures in a lake or reservoir are homogeneous from top to bottom. As summer advances, the surface waters become warmer and lighter than the underlying colder, denser waters. A thermal gradient or stratification is established in which various water layers can be defined (Figure i).

THERMOCLINE - the transition layer (Figure i) where rapid temperature change occurs between the upper warm water layer and the cold deep water layer. It is usually defined by a change in temperature of 1°C for each metre of water depth.

TROPHIC STATUS - depending on the degree of plant nutrient enrichment and resulting biological productivity, lakes are generally classified into three intergrading types: oligotrophic, mesotrophic and eutrophic. If the supply of plant nutrients to an extremely oligotrophic lake is progressively increased, the lake will become more mesotrophic in character; with further enrichment it will eventually become eutrophic.

INTRODUCTION

Early in October 1968, representatives of the Department of Municipal Affairs and Michael Hough Associates Limited, Landscape Architects and Site Planners, requested that a biological survey be conducted on Riley Lake in connection with a shoreline capability study. Although a minimum of sampling effort was possible, the report (Michalski, 1969) concluded that the lake was eutrophic and, "... it is certain that existing cottages and permanent homes are contributing factors in the enrichment of Riley Lake." Additionally, Michael Hough Associates Limited utilizing a number of parameters including soil conditions, lake morphometry, boating conditions, unique natural and scenic features concluded, "It is clear that Riley Lake is overdeveloped, and further development beyond existing approved lots should be prevented."

Biological and limnological aspects of the 1968 investigation were continued during the summer of 1969 by personnel of the Department of Health and the Ontario Water Resources Commission. The objectives of the study were to document fully the status of enrichment of Riley Lake and to provide a basis for considering the relationships between water quality and recognized uses.

GENERAL DESCRIPTION OF THE STUDY AREA

Riley Lake is located in the Township of Ryde, District of Muskoka, approximately 12 miles southeast of Gravenhurst (Figure 1) and 76 miles from Toronto. The lake is near the western boundary of the Black River Water-

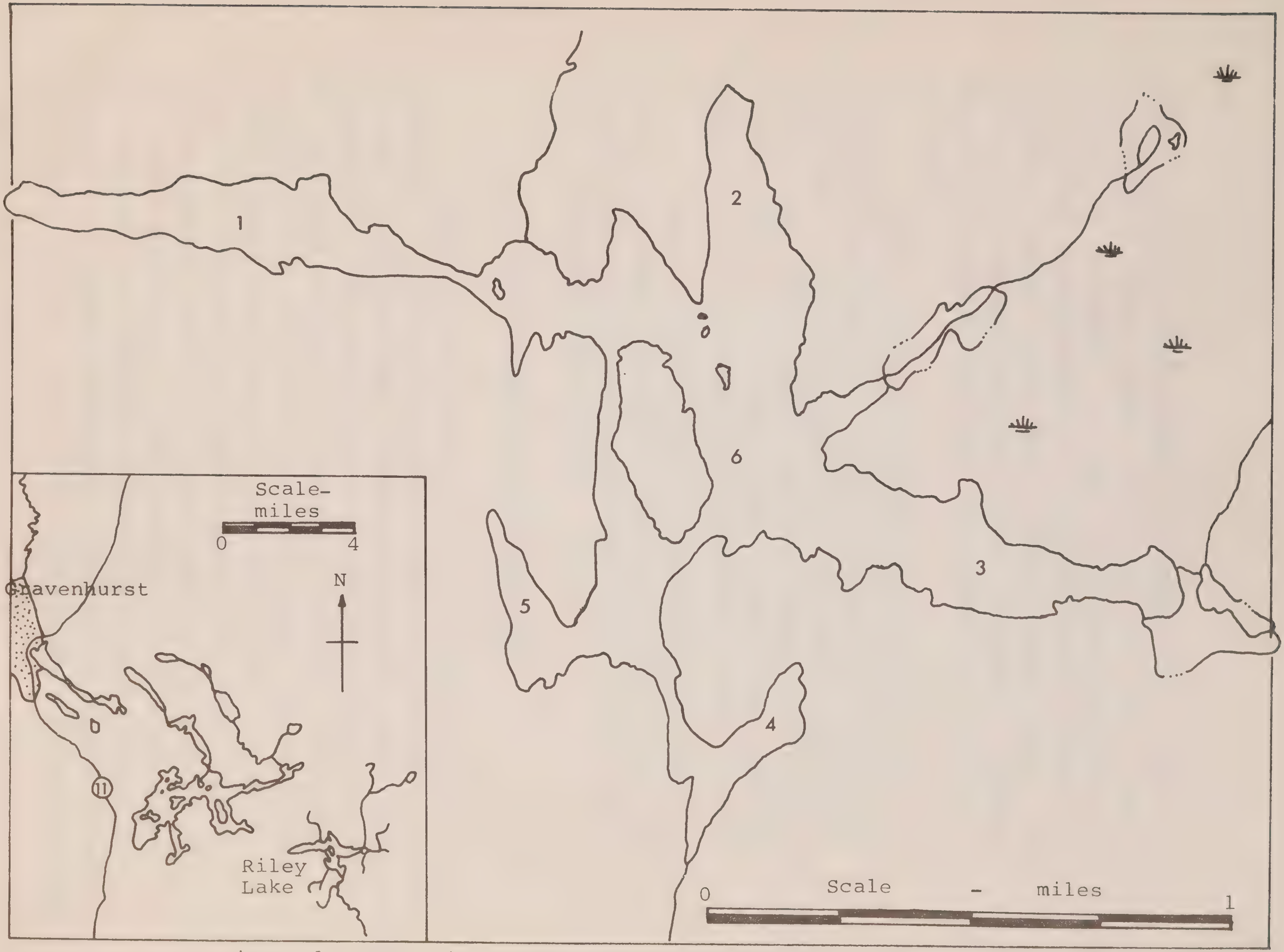


Figure 1. Location of six sampling sites in Riley Lake, 1969.

shed. It is "stellate-shaped" and appears to be spring-fed, although some drainage enters the lake from a swampy area to the northeast. A report of Kilborn Engineering Ltd. (1968) indicated that the lake had limited inflows and outflows of water, resulting in a small static volume. The lake has an estimated surface area of 350 acres, a maximum depth of 45 feet (13.5 m) and a mean depth of 19.5 feet (5.8 m).

An estimated 150 cottages surround Riley Lake. In addition, approximately 47 subdivided lots have been given final approval by the Department of Municipal Affairs and 13 lots have received draft approval (Michael Hough Associates Limited 1969). The final cottage density would therefore approximate 210, assuming all subdivided lots are developed.

Other pertinent data on topography, soil conditions, wildlife, climate, vegetation, scenic qualities, capability studies and sanitary wastes practices, etc., are available from the aforementioned reports.

EXPLANATION OF EUTROPHICATION

Lakes of north temperate regions have been classified trophically as oligotrophic, mesotrophic and eutrophic. Oligotrophic or "nutrient-poor" lakes are generally deep,clear,relatively unproductive and support cold-water species such as lake trout, whitefish and herring. In contrast, eutrophic lakes are usually turbid, warm, productive and contain warm-water game fish species such as walleye, pike, bass, perch and other less-valued species, for example catfish and carp. Lakes of intermediate types (e.g. Silver Lake near Port Carling) are termed mesotrophic. The transition from oligotrophic to eutrophic lakes progresses naturally owing to inputs of sediments and dissolved minerals associated with land run-off. These materials are retained and increase the nutrient potential

of the lake. The impact of sedimentation and gradual increases in levels of soluble phosphate, nitrate, calcium, silica, manganese and other mineral salts on phytoplankton production in a lake varies with climatic conditions, the shape and size of the lake basin, thermal conditions in the lake and colour and turbidity (which affects light penetration and hence the depth of the euphotic zone). As the lakes become shallower and warmer and concentrations of plant nutrients increase, they support increased phytoplankton populations, and attached forms of algae and vascular aquatic vegetation may develop. The lake is then in a eutrophic or enriched state. With time, decomposition products from the biota (living matter) and accumulations from inflowing tributaries fill the lake basin so that the lake takes on the physical and biological characteristics of a swamp or marshland. Generally, eutrophication is a slow process measured in geological time. However, it can be dramatically accelerated by artificial inputs from domestic and industrial wastes and agricultural run-off. In most lakes of significant size, it is unlikely that the progression from oligotrophy to eutrophy will occur in a single generation of man. However, in small lakes severely affected by artificial inputs of nutrients, classical indications of mesotrophy and/or eutrophy (for example, changes in benthic and planktonic abundance; species production and community associations; nutrient and dissolved oxygen concentrations; sediment types; fish production, etc.) will appear over relatively short-term periods.

METHODS

On twelve days between June 3 and September 25, 1969 physical, chemical and biological sampling was carried out at six locations (Figure 1) in Riley Lake by personnel of the

Public Health Engineering Service, Ontario Department of Health. On June 3, July 31 and September 25 additional data were collected by staff of the Biology Branch,Ontario Water Resources Commission. On the latter two dates estimates of primary productivity were made using the radioactive carbon - 14 technique. The work carried out by OWRC personnel was conducted only at Station 6.

A detailed account of the field and laboratory procedures is provided in APPENDIX A.

RESULTS

Physical aspects

Temperature

On June 3 a temperature difference of 9°C existed between surface (18°C) and bottom (9°C) waters at Station 6. By July 31 a well-defined thermocline or zone of rapid temperature change was found, commencing at 4.5 m. On this date the thermocline was characterized by a drop of 10°C in 3.5 m. By September 25 the thermocline was still apparent; however, it was positioned deeper in the lake than previously recorded. (Figure 2 a, b and c).

Light penetration

A summary of the Secchi disc readings is provided in Table 1. These readings may be used to calculate (X2) a theoretical euphotic zone or zone of algal production at the six sampling sites. Considering the summary for the locations, Station 4 was characterized by the lowest mean Secchi disc reading (1.5 m).

At Station 6 a low Secchi disc reading of 1.5 m was observed on July 31 and September 25, days when productivity estimates were carried out.

Table 1. Summary of chemical determinations (expressed in mg/l) made on samples collected from the euphotic zone of Riley Lake between June 3 and September 25, 1969.

	STATION 1			STATION 2			STATION 3			STATION 4			STATION 5			STATION 6		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Total Phosphorus (as P)	0.12	0.02	0.04	0.13	0.01	0.03	0.03	0.01	0.02	0.17	0.01	0.04	0.04	0.01	0.03	0.05	0.01	0.03
Total Kjeldahl (as N)	0.67	0.19	0.50	0.75	0.22	0.47	0.70	0.31	0.53	1.00	0.32	0.58	0.59	0.00	0.40	0.79	0.29	0.50
Free Ammonia (as N)	0.20	0.03	0.09	0.12	0.01	0.07	0.15	0.01	0.05	0.22	0.01	0.10	0.15	0.01	0.06	0.15	0.00	0.06
Nitrate (as N)	.078	.005	.012	.050	.006	.011	.050	.005	.010	.060	.006	.015	.060	.005	.011	.070	.003	.012
Silica (as SiO_2)	2.80	0.05	1.14	2.60	0.10	1.20	2.80	0.10	1.27	2.70	0.20	1.26	2.60	0.10	1.22	2.50	0.06	1.29
Iron (as Fe)	0.74	0.04	0.30	0.50	0.04	0.26	0.70	0.06	0.30	1.00	0.15	0.47	0.80	0.10	0.30	0.62	0.00	0.29
Alkalinity (as $CaCO_3$)	8	6	7	9	5	7	9	6	8	10	5	7	8	6	7	9	5	8
Secchi disc (m)	2.3	1.5	1.8	2.1	1.2	1.7	2.1	1.3	1.7	1.8	1.3	1.5	1.8	1.2	1.6	2.1	1.5	1.8

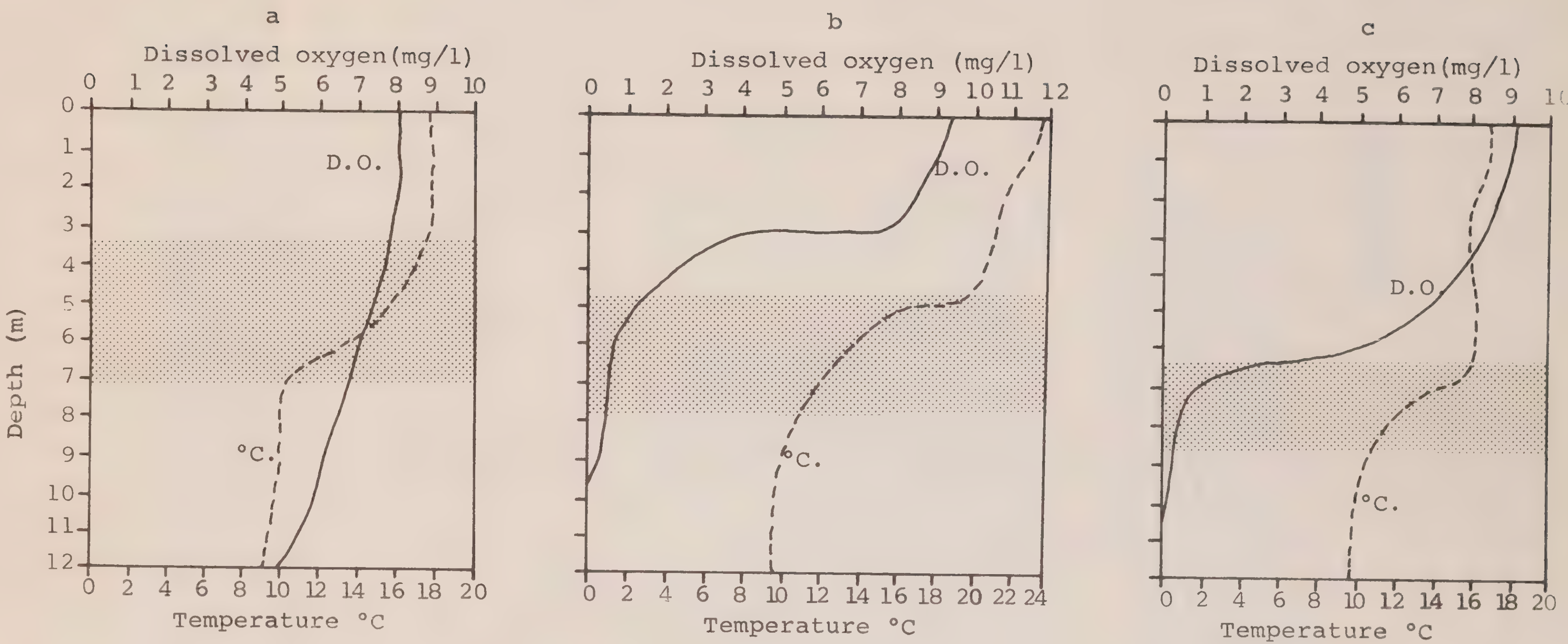


Figure 2. Profiles of dissolved oxygen (mg/l) and temperature (°C) at Station 6 in Riley Lake on June 3 (a), July 31 (b) and September 25 (c). Shaded areas approximate the position of the thermocline.

Chemical considerations

Alkalinity

Moyle (1949) considered a total alkalinity of 40 mg/l to be a natural separation point between soft and hard waters. The mean and extreme values for alkalinity at the six sampling locations are provided in Table 1. An average for all stations was 7.3 mg/l.

Dissolved oxygen

Clinograde oxygen distributions or reductions in oxygen concentrations in the deeper layers of the water were detected at Station 6 on the three occasions when intensive sampling was carried out (Figure 2 a, b and c).

On June 3 when samples were collected only from the 1 m and bottom strata at Station 6, oxygen saturations were 82% (7.8 mg/l) and 49% (5.6 mg/l), respectively. On July 31 oxygen levels decreased from 93% saturation (8.0 mg/l) at 1 m to 26% saturation (2.3 mg/l) at 4 metres of depth (Figure 2 b). Oxygen was not detected immediately above bottom on this occasion. On September 25, the surface waters were 90% saturated (8.8 mg/l). On this day oxygen levels were relatively stable to 6 m. However, a striking decline in the vertical oxygen regime was apparent as concentrations diminished from 56% saturation (5.7 mg/l) at 6 m to 5% saturation (0.5 mg/l) at 8 m (Figure 2 c).

pH

On occasions when pH data were collected at each metre of depth, the pH was higher in the surface waters than in the deeper strata (Figure 3 a, b and c). For example, on June 3 pH readings at 1 and 11 m were 7.8 and 5.7, respectively.

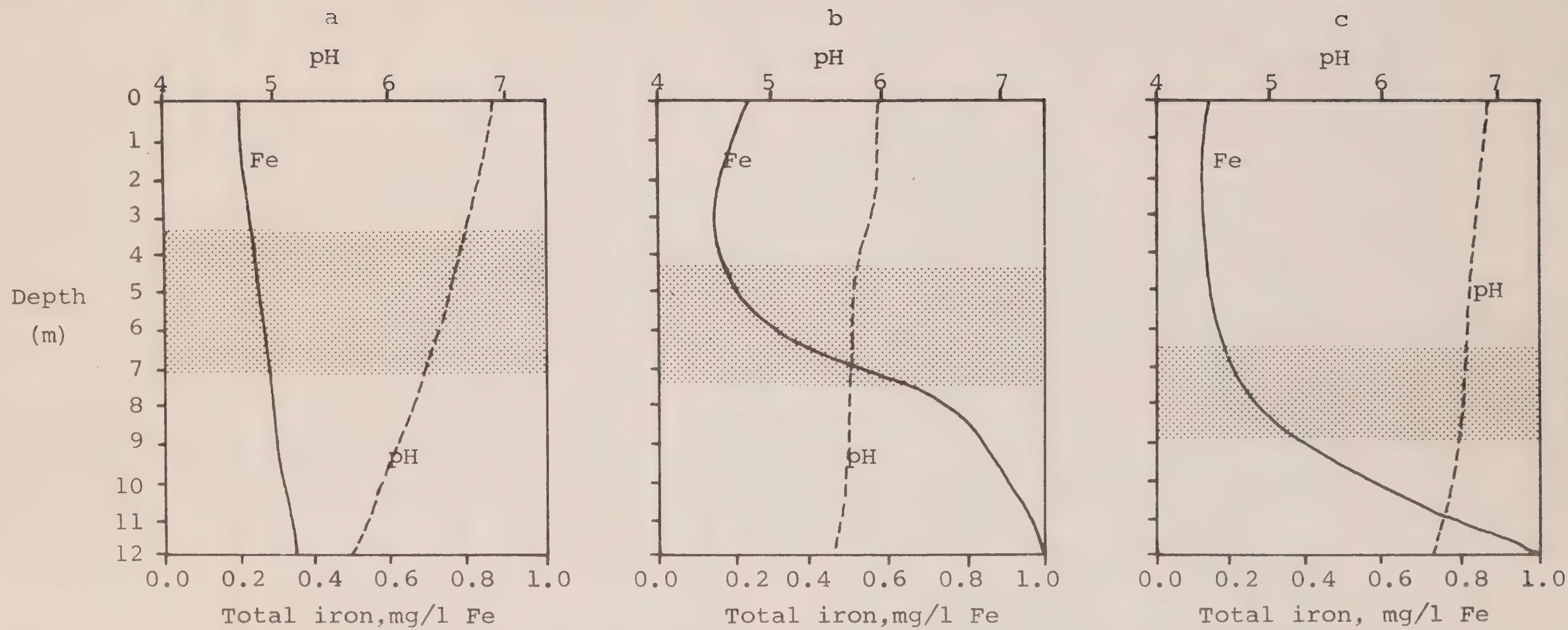


Figure 3. Profiles of pH and iron (as Fe) at Station 6 in Riley Lake on June 3 (a), July 31 (b), and September 25 (c). Shaded areas approximate the position of the thermocline.

Nutrient considerations

A summary of the nutrient data characterizing the euphotic zone of Riley Lake is provided in Table 1. Note that the mean values for total phosphorus, total Kjeldahl, free ammonia and nitrate nitrogen were highest for Station 4, the same Station where the lowest mean Secchi disc readings were recorded.

On June 3, July 31 and September 25 total phosphorus, total Kjeldahl and free ammonia nitrogen, as well as silica concentrations in the hypolimnion (zone of colder water below the stable thermocline), were considerably higher than those recorded from the warmer epilimnetic (above thermocline) waters (Figures 4 and 5). It is significant to note that iron concentrations (as Fe) increased with depth at Station 6 (Figure 3 a, b and c).

Phytoplankton populations and productivity

Standing stocks of phytoplankton - quantitative aspects

Figures 6, 7 and 8 summarize in chart form the quantitative and qualitative results for each sample at the six sampling locations. On the chart the bar graph or histogram (Percent Occurrence by Algal Groups) records for each individual count the relative percentage of the four main algal groups (i.e. blue-greens, flagellates, greens and diatoms). The line graph represents the total phytoplankton count measured in a.s.u. per ml. For example, the sample collected on August 26 from Station 6 had a total phytoplankton count of 1,817 a.s.u. per ml (as indicated by the figures on the left hand side of the chart); 44% of the total algae were blue-greens; 28% were diatoms; 19% were flagellates and 9% were green algae.

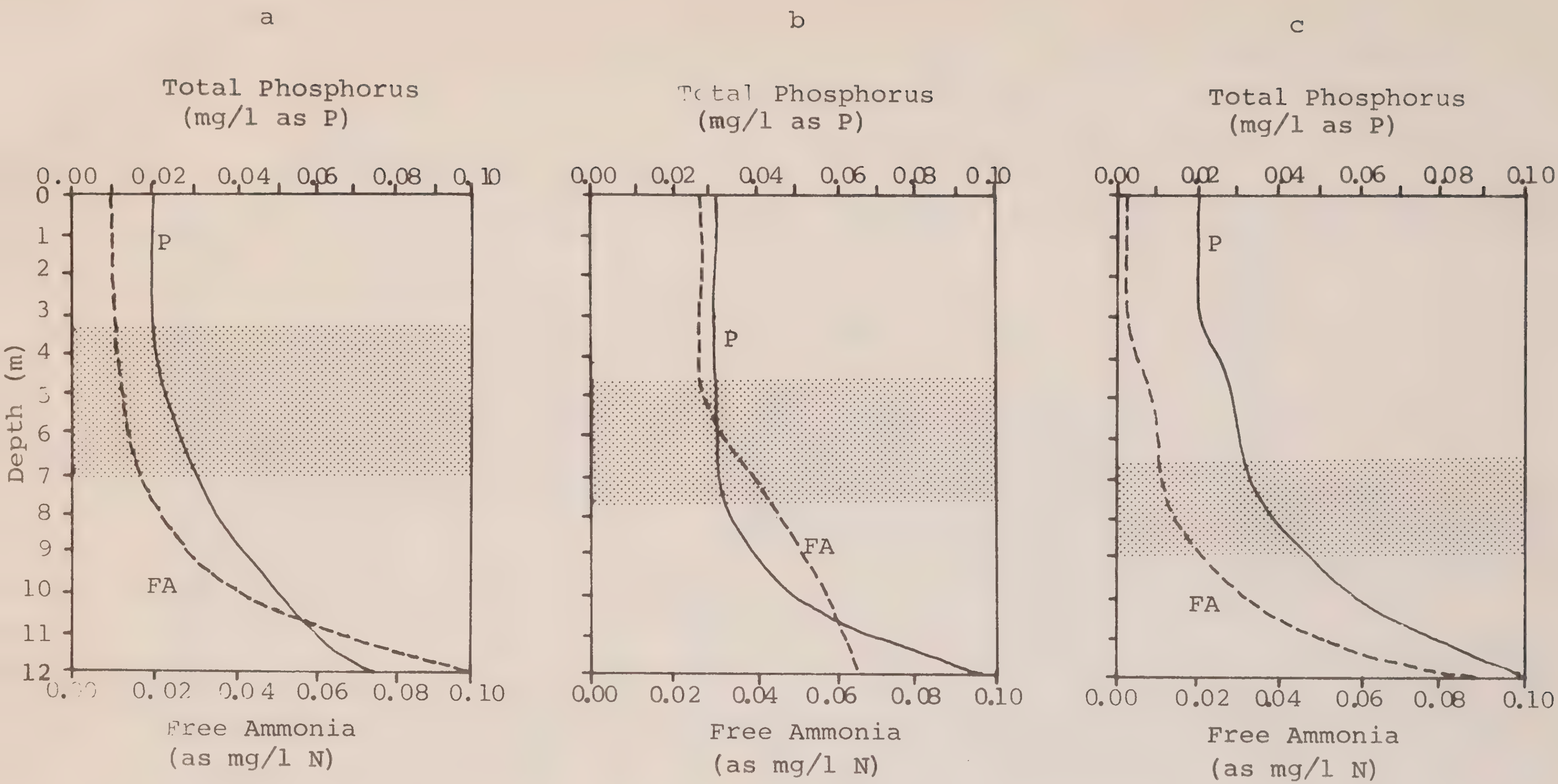


Figure 4. Profiles of total phosphorus (as P), and free ammonia (as N) at Station 6 in Riley Lake on June 3 (a), July 31 (b) and September 25 (c). Shaded areas approximate the position of the thermocline.

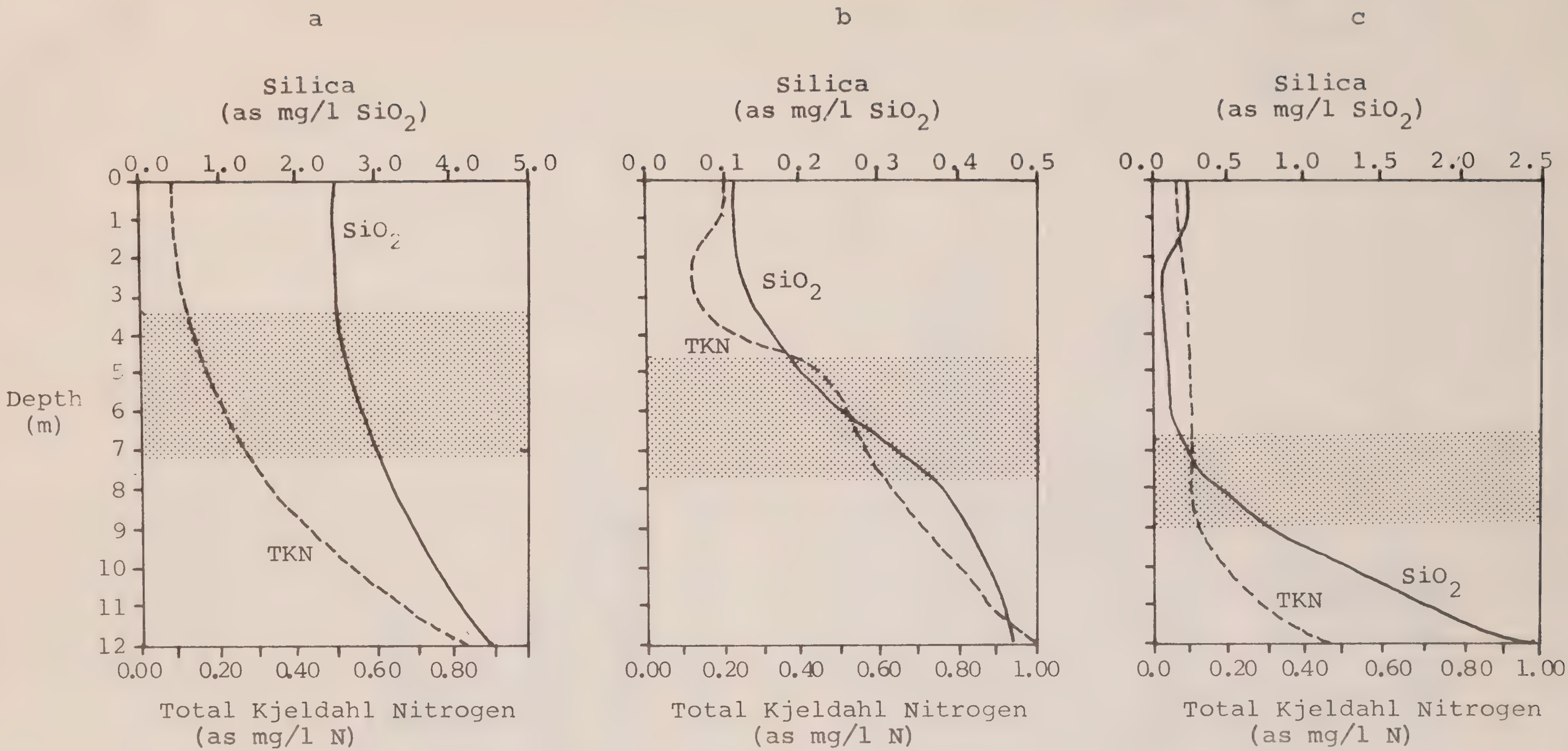


Figure 5. Profiles of silica (as orthosilicate) and total Kjeldahl nitrogen (as N) at Station 6 in Riley Lake on June 3 (a), July 31 (b) and September 25 (c). Shaded areas approximate position of the thermocline.

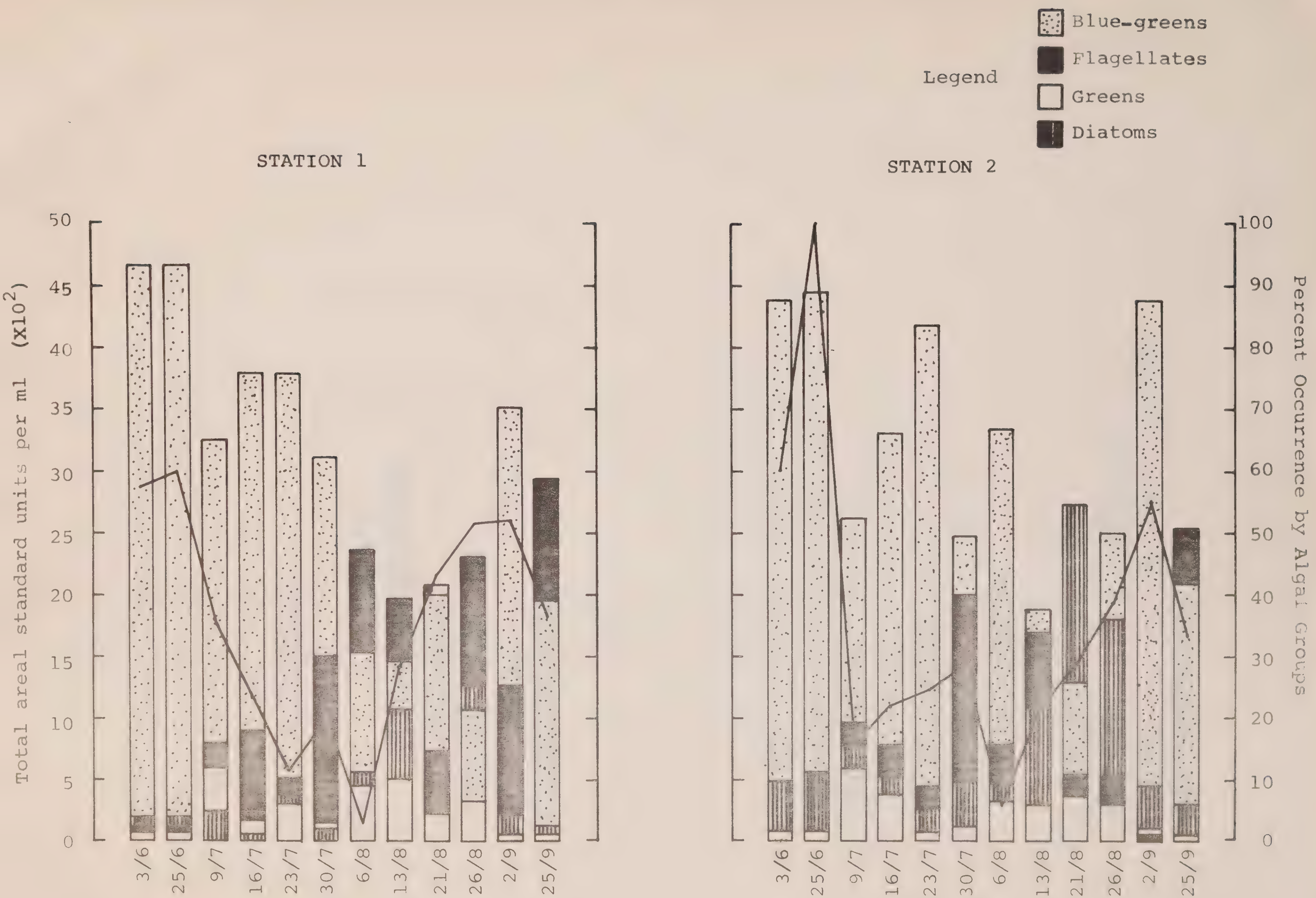


Figure 6. Standing stocks of phytoplankton at Stations 1 and 2 in Riley Lake, June 3 - September 25, 1969.

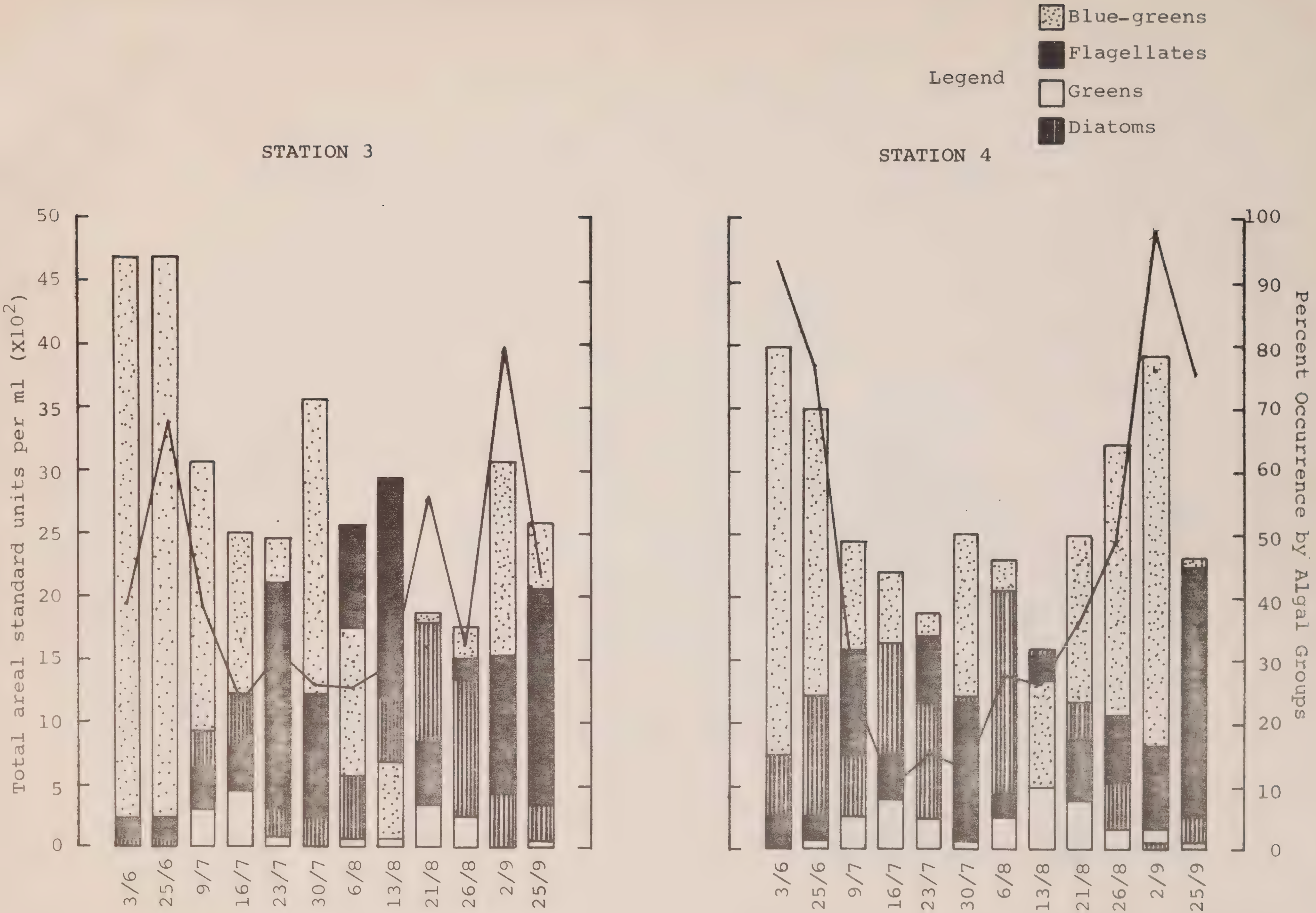


Figure 7. Standing stocks of phytoplankton at Stations 3 and 4, Riley Lake, June 3 - September 25, 1969.

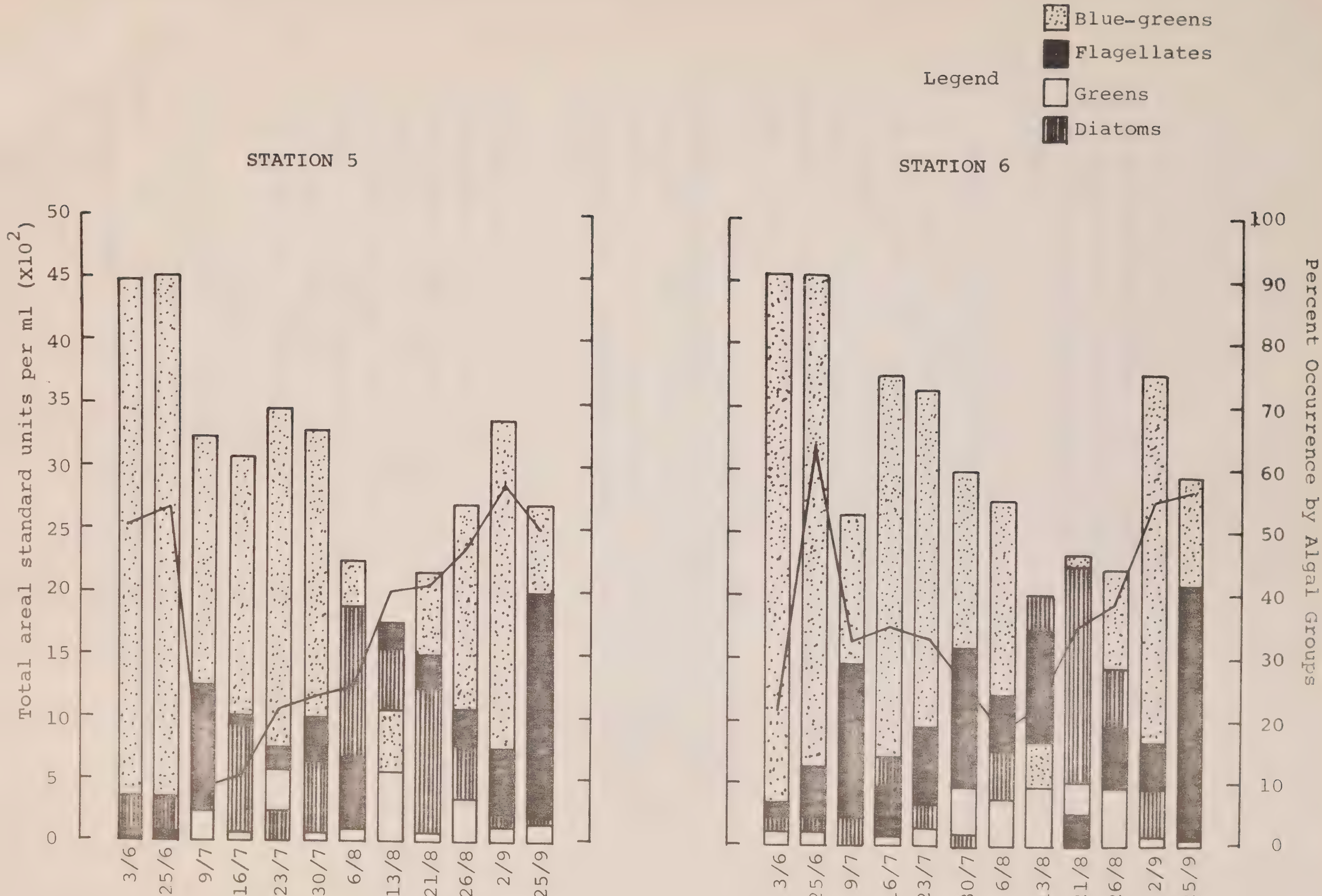


Figure 8. Standing stocks of phytoplankton at Stations 5 and 6, Riley Lake, June 3 - September 25, 1969.

Figures 6, 7 and 8 depict the seasonal pattern of phytoplankton development at the six sampling sites. Two maximum periods of phytoplankton production occurred, the first in June and the second during late August and early September.

Standing stocks of phytoplankton - qualitative aspects

Blue-green algae dominated during the entire sampling period but were particularly abundant during the two maximum periods of phytoplankton development. In general, mid-summer populations were characterized by a greater variety of species representing a number of taxonomic groups.

In June, the most important alga was the blue-green *Aphanizomenon flos-aquae*; highest numbers for this species occurred on June 25 at Station 2 where levels in excess of 4,600 a.s.u. per ml were recorded. The diatom *Tabellaria fenestrata* was sub-dominant at this time at all sampling sites.

In July and early August when standing stocks of phytoplankton were lowest, the flora was characterized by *Aphanizomenon flos-aquae*; the diatoms *Tabellaria fenestrata*, *Asterionella zasuminensis*, *Asterionella formosa* and *Melosira granulata*; the flagellates *Synura uvella*, *Ceratium hirundinella*, *Dinobryon bavaricum* and *Cryptomonas* spp. and the green algae *Oocystis pusilla*, *Dictyosphaerium ehrenbergianum*, *Dictyosphaerium pulchellum*, *Ankistrodesmus* spp., *Scenedesmus* spp., *Crucigenia* spp., *Staurastrum* spp. and *Tetraëdron* spp.

In contrast to the spring maximum when a single blue-green species (*Aphanizomenon flos-aquae*) dominated at all sampling sites, relatively high numbers of several blue-green species including *Anabaena affinis*, *Aphanizomenon flos-aquae*, *Lyngbya limnetica* and *Oscillatoria* spp. were observed

during the latter part of August and September. During this period the highest value (3,207 a.s.u. per ml) attributable to the blue-green grouping occurred on September 2 at Station 4 owing to the presence of *Anabaena affinis* (2,844 a.s.u. per ml), *Aphanizomenon flos-aquae* (259 a.s.u. per ml), *Chroococcus* spp., (81 a.s.u. per ml) and *Lyngbya limnetica* (23 a.s.u. per ml). In addition to blue-greens, relatively high numbers of flagellated algae prevailed. For example, on September 25 at Station 4, a total a.s.u. value of 2,718 was recorded, mainly owing to the abundance of *Synura uvella* (1,224 a.s.u. per ml) and *Chlamydomonas* spp. (123 a.s.u. per ml).

Species diversity

Table 2 summarizes the mean, maximum and minimum indices of diversity for each sampling date at the six locations. Generally, diversity values were lowest during June and early July and during the late summer. Thus, the index of diversity was inversely related to standing stocks of phytoplankton. For example, on August 6 when the lowest a.s.u. value (917) was recorded for Station 6, a relatively high(3.3) index of diversity was recorded. In contrast, on September 25 at the same location, corresponding values were 2,792 and 1.9.

Productivity per unit volume

Maximum hourly rates of carbon assimilation were approximately five times higher in July than in September (Table 3). On both occasions when productivity assessments were carried out, maximum rates were highest in the near surface waters. For example, rates of 94.2 and 56.8 mg $C/m^3/hr$ were recorded at 2.0 and 0.3 m on July 30 and September 25, respectively.

Table 2. Mean, maximum and minimum values of the Index of Diversity (I) for samples collected from the euphotic zone at six locations in Riley Lake, June 3 - September 25, 1969.

	Index of Diversity			
	No. Samples	Maximum	Minimum	Mean
Station 1	12	3.7	1.5	2.4
Station 2	12	4.4	1.9	2.7
Station 3	12	3.9	1.0	2.5
Station 4	12	4.3	1.7	3.2
Station 5	12	3.9	1.7	2.7
Station 6	12	4.3	1.9	2.7

Table 3. Measurements of carbon assimilation at selected depths (mg $C/m^3/hr$) and integrals of assimilation (mg $C/m^2/hr$) at Station 6, Riley Lake on two dates in 1969.

Depth (m)	July 31	Depth (m)	September 25
0.5	32.6	0.3	56.8
1.0	42.9	0.6	13.8
1.5	59.2	1.0	9.0
2.0	94.2	1.5	3.2
3.0	10.6	2.0	1.5
4.0	2.9	2.6	0.8
0 - 4.0	127.9	0 - 2.6	27.5

Areal productivity

In comparing the production of Riley Lake with other fresh water lakes, the integral or amount of carbon assimilated to the 1% light limit per square metre of surface is useful. Generally, it is assumed that photosynthetic carbon assimilation below the euphotic zone is considered to be negligible. Integrals of hourly productivity are presented graphically with standing stocks of phytoplankton (expressed as a.s.u. per ml) and transparency in Figure 9. Extrapolation of the hourly integrals to daily rates is provided in Table 6.

As indicated, absolute levels of carbon assimilation were higher in July (127.9 mg $C/m^2/hr$) than in September (27.5 mg $C/m^2/hr$). Considering depth, maximum standing stocks of phytoplankton coincided with optimum photosynthetic activity. On September 25, phytoplankters below a depth of 0.3 m were quite uniformly distributed.

DISCUSSION

Physical aspects

Secchi disc values are governed by the quantity of particulate suspended material (i.e. microscopic plants or phytoplankton, zooplankton, silt, etc.) and coloured matter (i.e. humus, tannins, etc.) in the water. In contrast to Riley Lake where the mean Secchi disc reading for 1969 was 1.6 m, readings were greater for both oligotrophic Lakes Joseph (8.1 m; unpublished OWRC data) and Bernard (4.1 m; Michalski and Robinson, 1969) and for mesotrophic Silver Lake (4.6 m; unpublished OWRC data, 1970). The primary factor contributing to differences in light penetration between the three lakes undoubtedly can be related to differences in phytoplankton abundance.

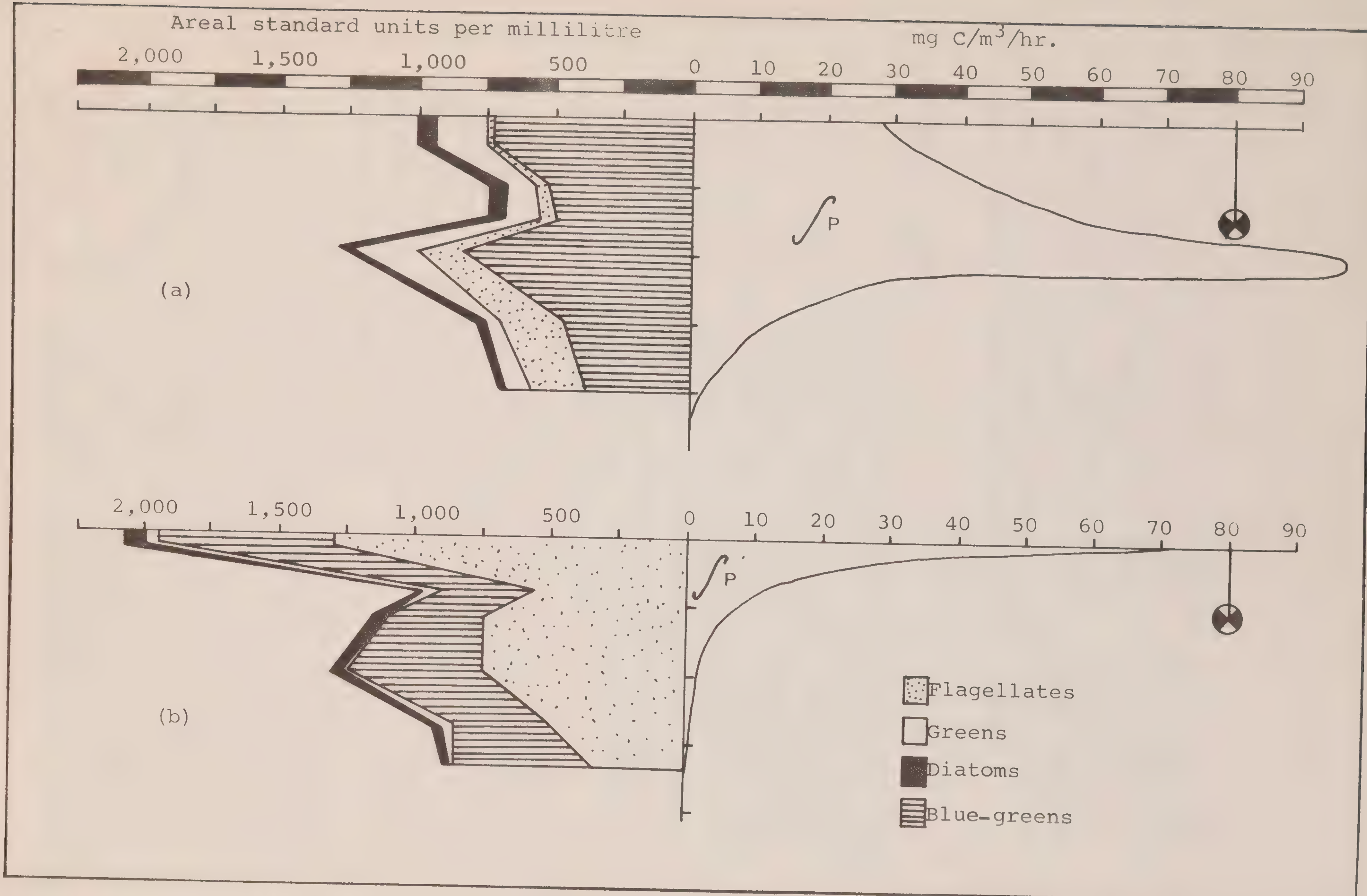


Figure 9. Vertical variation in carbon assimilation (mg $C/m^3/hr$) and standing stocks of phytoplankton (a.s.u. per ml) by taxonomic class at Station 6 in Riley Lake on July 31 (a) and September 25 (b). Extent of Secchi disc is shown.

A "lowering" of the thermocline (Figure 2 b and c) is a natural occurrence in many lakes. This "lowering" occurs as the epilimnetic zone deepens owing to temperature increase throughout the summer months. Resulting incorporation of the upper strata of the nutrient-enriched hypolimnion into the photic zone undoubtedly contributes to high production during late August and September.

Chemical aspects

The clinograde oxygen distribution curves detected at Station 6 in Riley Lake on June 3, July 31 and September 25 are characteristic of eutrophic lakes. The deep-water oxygen deficit is partially related to decomposition of the current year's production of algae following settling to the bottom. Additionally, oxidation of previous years' suspended and/or sedimented particulate matter is contributing to the depletion of the hypolimnion's oxygen supply. Undoubtedly both processes were responsible for the deoxygenation noted in the hypolimnion in Riley Lake.

The higher pH values in the surface waters (when compared with those in the hypolimnion) resulted from the reduction of free CO_2 and $Ca(HCO_3)_2$ during photosynthesis. The decrease in pH in hypolimnetic waters was accentuated by conditions of decomposition with corresponding CO_2 and $Ca(HCO_3)_2$ increases.

The vertical distribution of phosphorus during thermal stratification is quite different in nutrient-poor and productive lakes. In the former type of lake relatively little variation with depth exists in either soluble or total phosphorus. In productive lakes with clinograde oxygen curves there is an increase in both fractions in the hypolimnion. Such increases were detected in the hypolimnion of Riley Lake on June 3, July 31 and September 25 (Figure 4). The increases in total phosphorus are generally

dependent on sedimentation of plankton (Steiner 1938), whereas increases in soluble phosphorus are caused primarily by the liberation of phosphate from sediments on reduction (Einsele 1936). Of significance is the fact that the phosphorus fractions increased concomitantly with iron in the hypolimnion (Figure 3). Brydges (1970) points out that "... the formation of iron-phosphorus sediments under oxidizing conditions and their decomposition and release under reducing conditions are major factors in controlling the phosphorus concentrations in both the sediments and the lake water."

In oligotrophic lakes, little variation with depth in total Kjeldahl, free ammonia and nitrate nitrogen occurs. In contrast, small productive lakes are characterized by hypolimnetic increases of these nutrients (Figure 4 and 5). The increases are caused by bacterial decomposition and/or reduction processes.

Increases of silica in the hypolimnion (Figure 5) reflect the eutrophic condition of Riley Lake.

Phytoplankton communities

As demonstrated in Table 4, mean standing stocks of phytoplankton were slightly higher at Station 4 than elsewhere in the study area. These higher levels might be expected owing to the enclosed or cul-de-sac nature of this part of the lake and the fact that the sampling site is located on the windward side. Significantly, mean concentrations for total phosphorus, total Kjeldahl, free ammonia and nitrate nitrogen, as well as the mean Secchi reading, all reflect the accumulation of organic material at Station 4 owing to wind and wave action.

Table 4. Summary of phytoplankton data collected from various sources during the summer of 1969, except for the Georgian Bay information which was collected during the ice-free period of 1968. All results are expressed as a.s.u. per ml.

Municipality	Source	Sampling period	No.of samples	Areal standard units per ml		
				Maximum	Minimum	Mean
Penetang	Penetang Harbour	May 13-Oct.22	36	9,577	281	2,510
Collingwood	Georgian Bay	April 2-Dec.4	207	782	7	226
Grand Bend	Lake Huron	April 2-Sept.24	25	559	23	155
Union	Lake Erie (Western Basin)	May 8-Sept.29	26	7,147	1,022	3,190
Ottawa	Dow's Lake	May 14-Sept.24	20	13,651	455	5,581
Ryde Twp.	Riley Lake No.1	June 3-Sept.25	12	2,994	141	1,758
Ryde Twp.	Riley Lake No.2	June 3-Sept.25	12	5,056	458	1,865
Ryde Twp.	Riley Lake No.3	June 3-Sept.25	12	3,908	1,193	2,079
Ryde Twp.	Riley Lake No.4	June 3-Sept.25	12	4,811	649	2,256
Ryde Twp.	Riley Lake No.5	June 3-Sept.25	12	2,715	415	1,709
Ryde Twp.	Riley Lake No.6	June 3-Sept.25	12	3,104	917	1,808
Mean Values	Riley Lake	June 3-Sept.25	12	-	-	1,912

Table 4 provides a comparison of phytoplankton numbers from several sources. The data are based on collections of samples approximating the same period when sampling was carried out in Riley Lake, except for the samples taken in Georgian Bay near Collingwood. At Collingwood, data were obtained during the ice-free period of 1968; phytoplanktonic conditions in 1969 are assumed similar to those of 1968. It should be emphasized that water from the Collingwood and Grand Bend areas is undoubtedly typical of the general water quality throughout Georgian Bay and Lake Huron, respectively.

Standing stocks of algae in Riley Lake were exceedingly higher than those reported from Collingwood and Grand Bend, two municipalities located on the shorelines of unproductive waters. However, phytoplankton levels in the lake were of the same order of magnitude as those in Penetang Harbour, a decidedly eutrophic body of water, but were lower than those recorded from the Union Water Treatment Plant, which is situated along the northern shoreline of the enriched Western Basin of Lake Erie. Also, they fall short of those in Dows Lake, a relatively enclosed section of the Rideau River which is severely affected by artificial enrichment from municipal development and agricultural run-off.

The following comments relate to the ecology of the most important algal types observed in Riley Lake.

Phytoplankton communities dominated by *Aphanizomenon flos-aquae* and *Anabaena* spp., types which commonly form mid-summer and early fall "water-blooms", are characteristic of highly productive waters. The abundance of *Aphanizomenon flos-aquae* and three species of *Anabaena* reflect the eutrophic nature of Riley Lake.

The most abundant diatom, Tabellaria fenestrata was an exceptionally stable seasonal form. Most reports in the literature indicate that this species is capable of thriving under a wide range of ecological conditions. No definite conclusion therefore can be drawn relative to its relationship with various lake types. Asterionella formosa was one of the most important diatoms encountered in Riley Lake. In European lakes and in some North American waters, this species is associated with eutrophic conditions. On the other hand, Rawson (1956) reported that Asterionella formosa is characteristic of large oligotrophic Canadian lakes. Data collected by Biology Branch staff indicate this species to be ubiquitous, generally dominating during the spring seasons. Stoermer and Yang (1970) conclude, "The wide variety of habitat types occupied by this species and the presence of many minor variations in its morphology lead to the speculation that it has a number of ecological races or even that its present circumscription may include a number of separate species which are difficult to distinguish from morphological criteria." Ecological information regarding Asterionella zasuminensis is scarce. European taxonomists indicate this species is well known, especially in Poland, Sweden and Denmark where it usually exists in combination with Asterionella formosa. It has never been reported from North American waters. The development of relatively high numbers of Melosira granulata during July and August in Riley Lake should not be overlooked. According to Hustedt (1945) this is the diatom most characteristic of eutrophic waters in Europe.

In providing a classification of phytoplanktonic types, Hutchinson (1967) describes the eutrophic chlorococcal (green algae) plankton with the following statement, "A number of genera notably Pediastrum and Scenedesmus, but also

Actinastrum, *Ankistrodesmus*, *Crucigenia*, *Dictyosphaerium* and *Tetraëdron*, may be abundant in eutrophic waters, often in rather small lakes. The most usual dominants appear to be *Pediastrum* and *Scenedesmus*." As described earlier, *Dictyosphaerium*, *Ankistrodesmus*, *Scenedesmus*, *Crucigenia* and *Tetraëdron* were the most abundant green algae found during the study in Riley Lake.

Species diversity

The term diversity can be defined as a measure of the number of species (Hooper, 1969). High diversity populations are characterized by many kinds of animals or plants; in low diversity situations there is a limitation to a few species. The intensity of one or more environmental factors tends to limit the numbers of species and thereby lowers the diversity. Young (1956) and Margalef (1961) have indicated that increases in nutrient supply may effect a decrease in diversity. It is extremely difficult to make definite conclusions relative to the diversity - trophic status relationship as previous data on Riley Lake are not available. Table 5 provides a comparison between Dunlop and Riley Lakes. As indicated, minimum diversity values were similar; however, maximum and mean levels were substantially higher in the more unproductive waters of Dunlop Lake, an oligo-mesotrophic lake (Johnson *et al.*, 1970). These data imply that Riley Lake is in a more advanced state of eutrophication than is Dunlop Lake.

Primary productivity

Several explanations exist relative to the wide variations detected between the July and September primary productivity rates. Light and/or temperature limitations appear to offer the most logical explanation why carbon uptake

Table 5. Comparison of Indices of Diversity (I) of Riley Lake with those of Dunlop Lake.

Source	Index of Diversity		
	Maximum	Minimum	Mean
Riley Lake	4.4	1.9	2.7
Dunlop Lake (low productivity Northern Ontario lake)	12.3	1.6	5.9

rates were lower in September than in July. As outlined earlier, the depth to which optimum photosynthetic activity occurred(and correspondingly the extent of the euphotic zone) was lower in the water column in July than in September. Significantly,standing stocks of phytoplankton were higher during the latter carbon assimilation study. The resulting shading effect of near-surface phytoplankton populations, lower light intensities, depletion of available nutrients and reduced water temperatures or a combination of these factors may have been instrumental in suppressing rates of production.

The fact that phytoplankters were more uniformly distributed with depth in July than in September relates primarily to the abundance of the blue-green algae Anabaena spp. and Aphanizomenon flos-aquae in the surface waters during the latter period (Figure 9). These "water-bloom" species naturally congregate in the surface waters, having an adaptation to floating due to the development of gas vacuoles.

Elster (1954) pointed out that the photosynthetic capacity of a lake appeared to be an excellent criterion for establishing an absolute scale for comparing the trophic status between lakes. (Table 6). However, in comparing the data tabulated one must realize that a number of fundamental problems associated primarily with the methodology employed reduce the value of absolute measurements of production (Vollenweider, 1968); such differences must be kept in mind when comparing the productive rates between lakes.

On the basis of maximum volumetric and absolute daily rates, the values for carbon assimilation in Riley Lake were of the same order of magnitude as those of Penetang Harbour, Lake Furesø and Lake Esrom, three eutrophic situations,

Table 6. Comparison of maximum productivity rates of several lakes with those of Riley Lake.

Source	Maximum mg C/m^3/day	Maximum mg C/m^2/day
Penetang Harbour	509	1,513
Dunlop Lake	36	200
Riley Lake	942	1,279
Lake Furesø (Denmark)	700	1,840
Lake Esrom (Denmark)	500*	1,460**

* measured 3/8/56

** measured 20/8/56

but were exceedingly higher than those of Dunlop Lake, an oligotrophic to mesotrophic lake (Johnson, et al., 1970).

Findenegg (1964) pointed out that the characteristics of the vertical assimilation curves often provide a better indication of the trophic nature of a lake than do integrated daily yields or annual yields. Assimilation curves of Findenegg's Type I - eutrophic lake have a single characteristic; a near-surface maximum photosynthetic rate which decreases with depth. The decrease in carbon assimilation generally coincides with an exponential decrease in light. As depicted in Figure 9, Findenegg's Type I curve characterized the vertical assimilation of carbon at Station 6 on July 30 and September 19.

Sources of nutrients in Riley Lake

With the development of cottages around Riley Lake, artificial inputs of phosphorus, nitrogen and carbon from kitchen and laundry wastes and seepage from septic tanks have undoubtedly contributed to the nutritional buildup in the lake.

Probably one important nutrient source into Riley Lake has been through the use of household detergents since these products in the past have contained up to 50% by weight, phosphorus as PO_4. Phosphorus originating from detergents may gain access to the lake following dishwashing and laundering activities. Hutchinson (1967) pointed out, "In lakes in which large blooms of *Anabaena* occur it is probable that the nitrogen fixing activity of this alga may make significant contributions to the nitrogen undergoing biogeochemical transformation in the lake." Fixation of atmospheric nitrogen by *Anabaena* spp. may play an important role in the overall nutrient regime of Riley Lake.

Information presented in the March/April edition of Canadian Research and Development (1970) indicated that carbon was the key controlling element in eutrophication. In the following edition, Dr. J. R. Vallentyne refuted conclusively this claim by citing experiments carried out in laboratory flasks and in a series of experimental lakes in Northwestern Ontario. The lakes were characterized by inorganic carbon concentrations (0.2 to 5.0 mg/l) which were similar to those measured in Riley Lake (1.1 - 4.4 mg/l). The results indicated that significant growths developed in water enriched with nitrate and phosphate together. The effects of additions of carbon sources (i.e. CO_2, $NaHCO_3$, glucose, acetate) were negligible. It should be stressed that phosphorus is the only chemical element involved in stimulating eutrophication which is amenable to control.

Many authorities indicate that no conclusive evidence is yet available which clearly demonstrates that nutrients and/or bacteria originating from septic tank-tile field systems are gaining access to surface waters. Albeit, investigations on a number of recreational lakes in Precambrian cottage country have indicated that the lakes are ageing at accelerated rates. This knowledge has provided strong circumstantial evidence that waste inputs associated with cottage development are responsible for creating problems of enrichment. Assuming that present septic tank requirements are satisfactory, it would appear that many existing systems must either be malfunctioning or improperly installed. With specific emphasis on Riley Lake, Kilborn Engineering Ltd. (1968) indicated that this lake is situated in a highly problematical zone as soil conditions are extremely poor for the installation of septic tanks. The report further stated "... development should only be allowed in those areas where pockets of soil allow sufficient

absorption for septic tank installation." Michael Hough Associates Limited (1969) pointed out, "Two soil conditions required for proper tile bed usage, namely: well drained soil, and a minimum of 5 feet depth to rock, are not typically available over 75% of the total site."

A number of sewage disposal systems on Riley Lake should never have been constructed in view of water quality. It is unlikely that considerations have been given to various on-site features such as soil depth, soil type, slope, vegetative cover, depth to water table and distance to shoreline. In the past these variables, as well as the more intrinsic features of the septic tank - tile field area, have not been fully considered in assessing whether nutrient pollution and/or bacterial contamination will occur.

How much of the current production in Riley Lake can be attributed to artificial enrichment is open to question; nonetheless, it is believed that nutrients from domestic wastes have contributed to the overall nutrient buildup. With these points in mind future shoreline development on Riley Lake should not be considered unless facilities for total elimination of all domestic wastes and artificial nutrient seepage to the water are effected.

Significance of eutrophication in Riley Lake

Considering water uses the effects of eutrophication are undesirable in Riley Lake. Excessive production of blue-green algae impairs the recreational and aesthetic qualities of the lake by decreasing water clarity, and through the buildup of organic matter along the shoreline which decompose to create objectionable odours. Additionally, the water of Riley Lake will become increasingly unsuitable as a domestic source of supply for cottagers, and more expensive treatment facilities involving constant maintenance will be required.

Further, the loss of oxygen from the deeper, colder waters of the lake reduces the suitable area for game fish and creates a further limitation on fish production through elimination of desirable fish-food organisms.

Control of nuisance algal growths

The only established method of chemical control involves the use of an algicide such as copper sulphate. This chemical can be applied only under the authority of a permit issued by the OWRC and large-scale applications must be closely supervised. It should be emphasized that chemical control measures provide only temporary relief and two or more treatments might be required each year. It is likely that most cottagers on the lake will consider this solution as economically impractical.

Can eutrophication in Riley Lake be controlled? Vollenweider (1968) states "The outlook appears brighter for individual cases, particularly where relatively small bodies of water with thickly-settled supply basins and well-defined sources of nutrients are concerned... Furthermore, there is no doubt that the elimination of local sources of pollution can bring about a considerable improvement in the overall condition of a lake, regardless of its surface area and its depth. However, it is to be feared that deep lakes in which over-enrichment is already pronounced cannot be restored to their original state, and that recourse to specific reclamation measures will do little to achieve speedy improvement of the overall condition of such lakes." In Riley Lake, correction of inadequate cottage waste treatment systems would undoubtedly reduce the current rate of eutrophication, but may not lead to improvement of existing conditions.

APPENDIX A

Field methods

Routine sampling

On twelve days between June 3 and September 25, 1967, physical, chemical and biological sampling was carried out at six locations (Figure 1) in Riley Lake by personnel of the Public Health Engineering Service, Ontario Department of Health. On these occasions an index of light penetration was obtained by means of a Secchi disc. Subsequently, biological and chemical samples were collected by lowering a 40-ounce bottle provided with a restricted inlet to the approximate location of the 1% incident light level (determined as twice the Secchi disc). The biological samples were preserved with enough Lugol's iodine at the time of sampling to impart a dark orange colour to the water. All samples were returned to the OWRC laboratories in Toronto for analyses.

On June 3, July 31 and September 25 additional physical, chemical and biological data were collected by staff of the Biology Branch, Ontario Water Resources Commission. This field work was conducted only at Station 6. All chemical samplings (carried out using a Van-Dorn water sampler) and physical readings were taken at every metre of depth. Temperature readings were made using a telethermometer. Dissolved oxygen concentrations were established using the Winkler method. Manganese sulphate, alkalide azide and sulphuric acid re-agents were added in the field while titration with 0.0045N sodium thiosulphate solution was carried out in the mobile laboratory located at Port Carling. Readings of pH were made by means of a PORTO-matic pH meter - Model 175 (Instrumentation Laboratories Inc.).

Primary productivity

On July 31 and September 25, 1969 estimates of primary productivity were made at Station 6 in Riley Lake using the radioactive carbon -14 technique. Samples of lake water were collected using a Van-Dorn bottle from six depths to 3.5 m on July 31 (approximate location of the 1% incident light level), and to 2.4 m on September 25. Water from each depth was dispensed into three clear and one dark (opaque) glass-stoppered 190-ml bottle. Additionally, a 40-ounce aliquot for inorganic carbon analyses was taken from the same Van-Dorn sample as the primary productivity sub-samples. NaOH was added to attain a final pH of approximately 12.5 to stabilize the inorganic carbon and to minimize biological activity.

One millilitre of radioactive carbon as sodium bicarbonate ($NaH^{14}CO_3$ of 100μ gm in 1.0 ml with activity of 10μ Ci) was added to each bottle using a calibrated hypodermic syringe. Care was taken to ensure that the clear bottles were not exposed to light during innoculation. The bottles were clamped in spacers and suspended at the depths from which the original sample was collected (Figure 10 a and b). Care was taken to avoid shading effects of the float. Effects of wave action on the float-suspension system undoubtedly assisted in maintaining the phytoplankton in suspension. An incubation period of 4-5 hours was used as this appears adequate for significant uptake of carbon fixation and yet sufficiently limited to minimize bottle effects (Vollenweider and Nauwerck 1961).

During the incubation period, 40-ounce samples were collected for phytoplankton analyses from depths similar to those of the *in situ* samples. These samples were treated as previously documented.

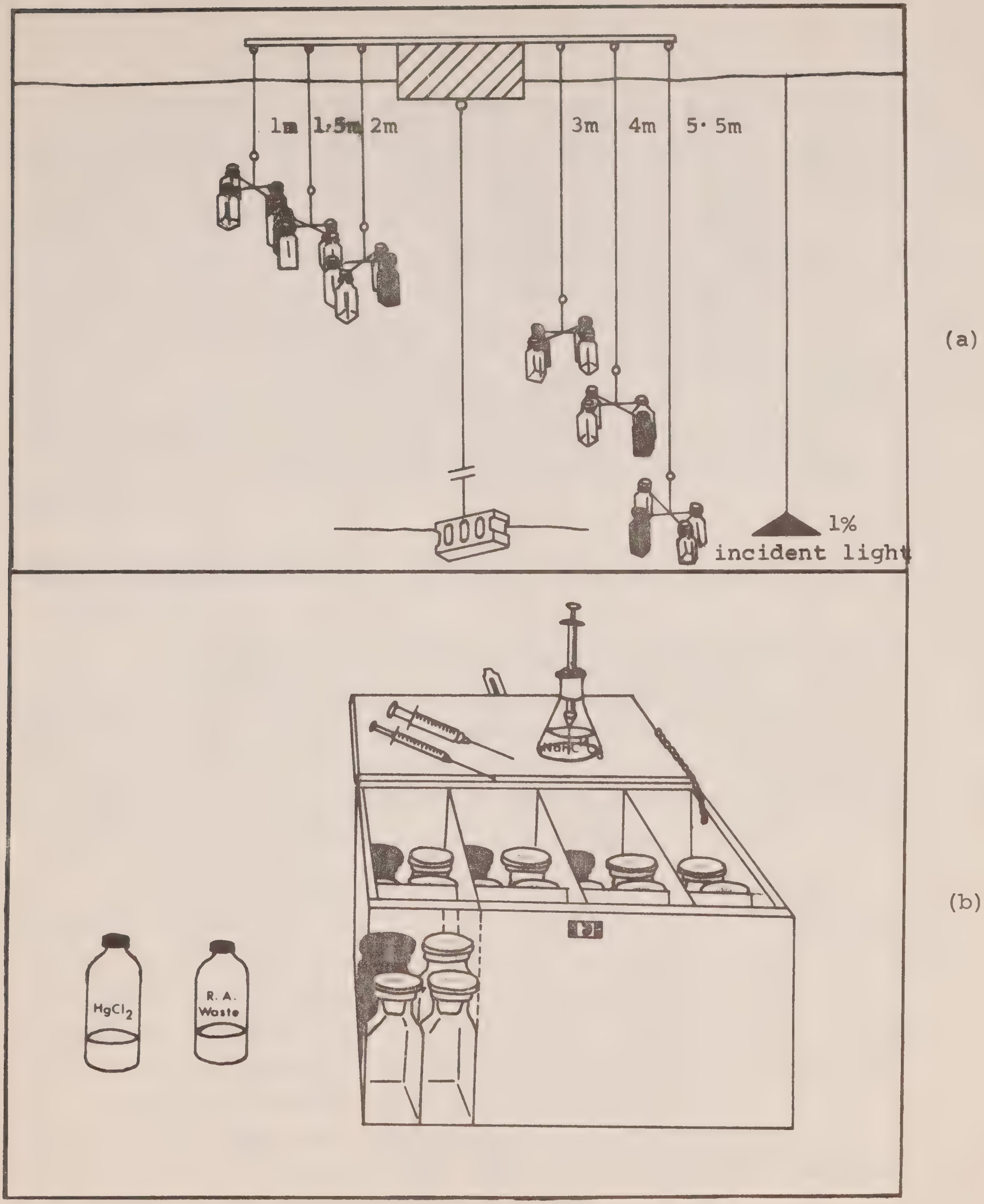


Figure 10. Diagrammatic representation (a) for determining photosynthetic activity of photic zone and (b) of field equipment: 10 ml syringe; 25 ml syringe; 1 ml syringe and sterile ^{14}C reservoir; light and dark bottles; $HgCl_2$ and container for radioactive waste material.

At the termination of the incubation period, primary productivity was arrested by adding mercuric chloride (0.7 gm per 1000 ml water) and, within several hours, the algae were removed on 0.45μ Millipore filters using a vacuum pump and pressure not exceeding 75 cm of mercury. Each filter was rinsed with four separate aliquots of distilled water, dried using an IR light source at a distance of 2 - 0.3 m and placed in a scintillation-counting medium of 0.01% POPOP and 0.4% PPO in toluene. The samples were transported to the laboratories in Toronto where the ^{14}C-activity of algae was determined with a Packard Tricarb spectrometer.

Laboratory methods

Chemistry

Nutrient analyses were performed on the chemistry samples for nitrogen (total Kjeldahl, nitrate and free ammonia nitrogen as mg N/l), total and soluble phosphorus (as mg P/l), orthosilicate (as mg SiO_2/l), iron (as mg Fe/l) and alkalinity (as mg $CaCO_3$/l). All analyses were conducted following standard procedures (A.P.H.A. et al. 1965).

In estimating the rate of carbon assimilated by algae it is necessary to know the concentration of inorganic carbon in the water. Calculation of inorganic carbon (bicarbonate and free CO_2) based on pH, alkalinity and temperature of titration (A.P.H.A. et al. 1965, Saunders et al. 1962) was not advisable because of the low levels present in pre-Cambrian soft-water lakes (Johnson et al. 1970). A technique was employed which concentrated inorganic carbon in the original 40-ounce sample bottle to a desired precision of 0.1 mg/l (Johnson and Michalski 1970).

Primary productivity

The uptake of carbon (^{12}C assimilated) by phytoplankton was estimated from the equation:

$$\frac{^{12}C \text{ assimilated}}{^{12}C \text{ available } (W + X)} = \frac{^{14}C \text{ assimilated } (Y)}{^{14}C \text{ available } (Z)} \cdot k$$

from which

$$^{12}C \text{ assimilated} = k \cdot \frac{Y}{Z} \cdot (W + X) \text{ mg C/m}^3$$

where

Y is the activity of filtered phytoplankton corrected for dark-bottle assimilation

W is the inorganic carbon concentration in the lake water (mg C/m^3)

X is the concentration of inorganic carbon added to the bottles (mg C/m^3) and

Z is the activity of inorganic carbon added to the bottles.

The estimates of assimilation (mg C/m^3/hr) from the various depths were presented graphically to determine absolute amounts of production per unit surface area (mg C/m^2/hr). Daily estimates were calculated on the basis of 10 hours insolation per day.

Phytoplankton analyses

The algal samples were concentrated by allowing the cells to settle for 72-96 hours, and the overlying liquid was then syphoned or decanted. Subsequently, the cells were re-suspended in a 25-ml concentrate and a 1-ml aliquot was transferred into a Sedgwick-Rafter counting cell. Most of the algal forms were identified to genus at a magnification of 220X. Where accurate identifications were impossible,

wet mounts were prepared and examined at higher magnifications. Quantitative results were expressed as areal standard units per millilitre. One areal standard unit is equal to an area of 400 square microns (Whipple 1914). Depending on the density of the concentrate, strips or fields were counted. Between 250 and 600 organisms per aliquot were identified and measured. The diatoms were speciated by acid digestion of a 15-ml portion of the concentrate,followed by mounting in Hyrax. These algae were examined at a magnification of 1200X or 1500X. These forms were counted by starting at one edge of the coverslip and scanning one or more rows across the mount. Valves were counted as one-half frustule; broken valves were not included in the countings. Conversion to areal standard unit values was accomplished by direct proportion.

The index of diversity, I (after Margalef 1958) for each of the photic zone samples was calculated as:

$$I = (S-1)/\log_e N$$

where

S is the total number of species observed and N is the total number of observed individuals.

APPENDIX B

List of phytoplanktonic species encountered in samples collected from Riley Lake, June 3 - September 25, 1969.

Bacillariophyceae

- *Achnanthes lanceolata* (Breb.) Grunow
- *Amphora* spp.
- *Asterionella formosa* Hassal
- *A. zasuminensis* (Cabejsz.) Lundh-Almestrand
- *Cocconeis placentula* Ehrenberg
- *Cyclotella antiqua* W. Smith
- *C. bodanica* Eulenstein
- *C. comta* (Ehr.) Kützing
- *C. glomerata* Bachmann
- *C. ocellata* Pantocsek
- *Cyclotella* spp.
- *Cymbella gracilis* (Rabh.) Cleve
- *C. perpusilla* Cleve
- *C. ventricosa* Kützing
- *Cymbella* spp.
- *Diatoma* spp.
- *Eunotia Meisteri* Hustedt
- *E. monodon* Ehrenberg
- *E. pectinalis* (Dillw.? Kütz.) Rabenhorst
- *E. praerupta* Ehrenberg
- *E. robtusa* Ralfs
- *E. septentrionalis* Østrup
- *E. sudetica* O. Müller
- *E. tenella* (Grun.) Hustedt
- *E. valida* Hustedt
- *Eunotia* spp.
- *Fragilaria construens* (Ehr.) Grunow
- *F. crotonensis* Kitton
- *Fragilaria* spp.

Frustulia rhomboides (Ehr.) De Toni
F. rhomboides var. saxonica (Rabh.) De Toni
Gomphonema olivaceum (Lyngb.) Kützing
Melosira ambigua (Grun.) O. Müller
M. granulata (Ehr.) Ralfs
M. italica (Ehr.) Kützing
Melosira spp.
Navicula cryptocephala Kützing
N. inflexa (Greg.) Ralfs
N. minima Grunow
N. pupula Kützing
N. radiosa Kützing
N. seminulum Grunow
N. viridula var. rostellata (Kütz.?) Cleve
Navicula spp.
Neidium dubium (Ehr.) Cleve
N. iridis (Ehr.) Cleve
Nitzschia gracilis Hantzsch
N. palea (Kütz.) W. Smith
N. paleacea Grunow
N. recta Hantzsch
N. vermicularis (Kütz.) Grunow
Pinnularia boyeri Patrick sp. nov.
P. Braunii (Grun.) Cleve
P. divergens (?) W. Smith
Pinnularia spp.
Rhizosolenia eriensis H.L.Smith
Stauroneis phoenicentron Ehrenberg
Stenopterobia (?) Brebisson
Surirella Capronii Brebisson
S. elegans (?) Ehrenberg
S. linearis W. Smith
S. papillifera Hustedt
S. robusta Ehrenberg
Surirella spp.

Synedra minuscula (?) Grunow
S. nana Meister
S. rumpens Kützing
S. tenera W. Smith
S. Vaucheriae Kützing
Synedra spp.
Tabellaria fenestrata (Lyngb.) Kützing
T. flocculosa (Roth.) Kützing

Chlorophyceae
Actinastrum sp.
Ankistrodesmus falcatus (Corda) Ralfs
A. falcatus var. acicularis (A. Braun) G.S.West
A. fractus (West & West) Brunnthaler
Ankistrodesmus spp.
Arthrodesmus sp.
Botryococcus Braunii Küetzing
Chlamydomonas Bergii Nygaard
C. epiphytica G. M. Smith
C. gloeophila Skuja
Chlamydomonas spp.
Chlorella spp.
Chlorogonium sp. Ehrenberg
Coelastrum sp.
Cosmarium spp.
Crucigenia apiculata (Lemm.) Schmidle
C. quadrata Morren
C. tetrapedia (Kirchner) W. & G. S. West
Crucigenia spp.
Dictyosphaerium Ehrenbergianum Naegeli
D. pulchellum Wood
Elakatothrix gelatinosa Wille
Elakatothrix spp.
Kirchineriella spp.

Micractinium pusillum Fresenius

Mougeotia spp.

Oocystis Borgei Snow

O. parva W. & G. S. West

O. pusilla Hansgirg

Oocystis spp.

Pandorina spp.

Pediastrum spp.

Quadrigula Chodatii (Tan.-Ful.) G.M.Smith

Q. closterioides (Bohlin) Printz

Scenedesmus arcuatus Lemmermann

S. obliquus (Turpin) Kützing

S. quadricauda (Turpin) Brebisson

Scenedesmus spp.

Schroederia Judayi G. M. Smith

Schroederia spp.

Selenastrum minutum (Naeg.) Collins

Sphaerocystis schroeteri Chodat

Spondylosium planum (Wolle) West & G.S.West

Staurastrum leptacanthum Nordstedt

S. megacanthum Lundell

Staurastrum spp.

Tetraëdron trigonum var. gracile (Reinsch) DeToni

Treubaria setigerum (Archer) G.M.Smith

Ulothrix variabilis Kützing

Chrysophyceae

Chrysosphaerella longispina Lauterborn

Dinobryon bavaricum Imhof

D. cylindricum Imhof

D. tabellariae (Lemm.) Pascher

Dinobryon spp.

Synura uvella Ehrenberg

Uroglenopsis spp.

Cryptophyceae

<u>Cryptomonas</u> <u>erosa</u> Ehrenberg

Dinophyceae

<u>Ceratium</u> <u>hirundinella</u> (O.F.Muell) Dujardin

<u>Glenodinium</u> <u>armatum</u> Levander

<u>G.</u> <u>Borgei</u> (Lemm.) Schiller

<u>Peridinium</u> <u>limbatum</u> (Stokes) Lemmermann

Euglenophyceae

<u>Euglena</u> spp.

<u>Phacus</u> <u>longicauda</u> (Ehrenberg) Dujardin

<u>P.</u> <u>triqueter</u> (Ehrenberg) Dujardin

<u>Trachelomonas</u> spp.

Myxophyceae

<u>Anabaena</u> <u>affinis</u> Lemmermann

<u>A.</u> <u>flos-aquae</u> (Lyngb.) Brebisson, ex Bornet & Flahault

<u>Anabaena</u> spp.

<u>Anacystis</u> spp.

<u>Aphanizomenon</u> <u>flos-aquae</u> (L.) Ralfs

<u>Aphanocapsa</u> spp.

<u>Aphanothece</u> <u>Castagnei</u> (Breb.) Rabenhorst

<u>A.</u> <u>clathrata</u> W. & G. S. West

<u>A.</u> <u>nidulans</u> P. Richter

<u>Chroococcus</u> <u>dispersus</u> (Keissler) Lemmermann

<u>C.</u> <u>limneticus</u> Lemmermann

<u>Chroococcus</u> spp.

<u>Dactylococcopsis</u> <u>acicularis</u> Lemmermann

<u>D.</u> <u>Smithii</u> Chodat & Chodat

<u>Gloeothece</u> spp.

<u>Gomphosphaeria</u> <u>aponina</u> Kützing

<u>G.</u> <u>lacustris</u> Chodat

<u>Lyngbya</u> <u>limnetica</u> Lemmermann

<u>Lyngbya</u> spp.

<u>Merismopedia</u> <u>tenuissima</u> Lemmermann

Oscillatoria curviceps C. A. Agardh

Phormidium sp.

Rhabdoderma Gorskii Wotoszynska

Spirulena princeps (West & West) G. S. West

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